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RESULTS OF A DEEP-TOW MULTICHANNEL SURVEY ON THE BERMUDA RISE

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Abstract. High-resolution multichannel seismic data taken with a deep-towed source and receiving array are used to obtain estimates of the *in situ* compressional velocity-depth functions within the upper ~300 m of deep-ocean sediments. These data, taken on the Bermuda Rise in an area with a nominal water depth of 5 km, resolve structure consistent with DSDP data from the region. The velocity-depth functions derived from these data indicate little P-velocity gradient in the upper 100-170 m of sediments and resolve P-velocity inversions within the depth range sampled.

Introduction

The Naval Ocean Research and Development Activity (NORDA) has developed the Deep Towed Array Geophysical System (DTAGS), a multichannel seismic system with which both the 250-650 Hz bandwidth source and 24-channel (42-m group spacing) array are towed at full ocean depths [Gholson and Fagot, 1983]. The design goal for DTAGS is to obtain high-resolution estimates of the structure and elastic properties of deep-ocean sediments that are not resolved in deep water by conventional surface-tow seismic systems. The geometry achieved by towing near the sea floor (500 to 700 m above the bottom for profiles presented here) and the relatively high-frequency (250 to 650 Hz) seismic source allow us to define the fine-scale structure of the upper sediments and to obtain estimates of the P velocities within those sediments. In this paper we report on seismic data gathered during a two-day period following the completion of the final engineering tests of DTAGS.

The data were taken in 1984 south-southwest of Bermuda on the Bermuda Rise (Figure 1) in a region with a nominal 5 km water depth. The Bermuda Rise is a northeast-southwest elongated tectonic arch, rising to depths approximately 1 km shallower than those of the surrounding Hatteras, Nares, and Sohm Abyssal Plains of the western North American Basin. The western side of the Rise, where the DTAGS data were taken, exhibits gently rolling topography broken by occasional basement peaks [Heezen et al., 1959; Johnson and Vogt, 1971; Bowles, 1980].

Control on the sediment composition and structure in the study area is available from data taken at DSDP Site 386 (located approximately 180 km to the east of our study area) and from Site 387, which is located approximately 200 km to the north-northwest of the study area (Figure 1). The ship used for the DTAGS study (R/V *Columbus Islen*) was not equipped with a standard seismic profiling system; therefore, there are no conventional seismic profiles coincident with the DTAGS data.

Ship's navigation was based on satellite fixes with dead-reckoning interpolation between fixes. Thus, the precise navigation required for common depth point (CDP) profiles was not available for this cruise. Data analysis, interpretation, and the seismic sections presented in this paper (Figure 2) are done in common shot point (CSP) format.

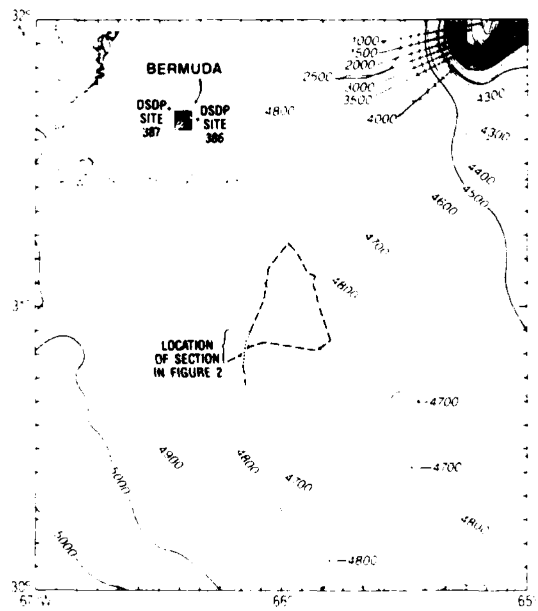

Fig. 1. The location of the DTAGS profile together with the locations of DSDP sites 386 and 387 and the island of Bermuda.

Seismic Observations

Each seismic data channel is digitized at 3125 samples/sec within the deep-tow subsystem. These data are multiplexed with engineering information (depth, heading, speed, etc.) and the entire data stream is transferred to the surface recording/monitoring system via a coaxial cable. The data are demultiplexed and stored on magnetic tape in SEG-D format.

Corrections for the array geometry were applied in the following manner. Ten pressure sensors are located along the seismic array and at the source module. This information was used to correct the seismic data to the depth of the source. The deviation of the array from the horizontal was less than 10°; the residual scatter in NMO corrected data is <0.004 sec. Direct water-wave travel times to each

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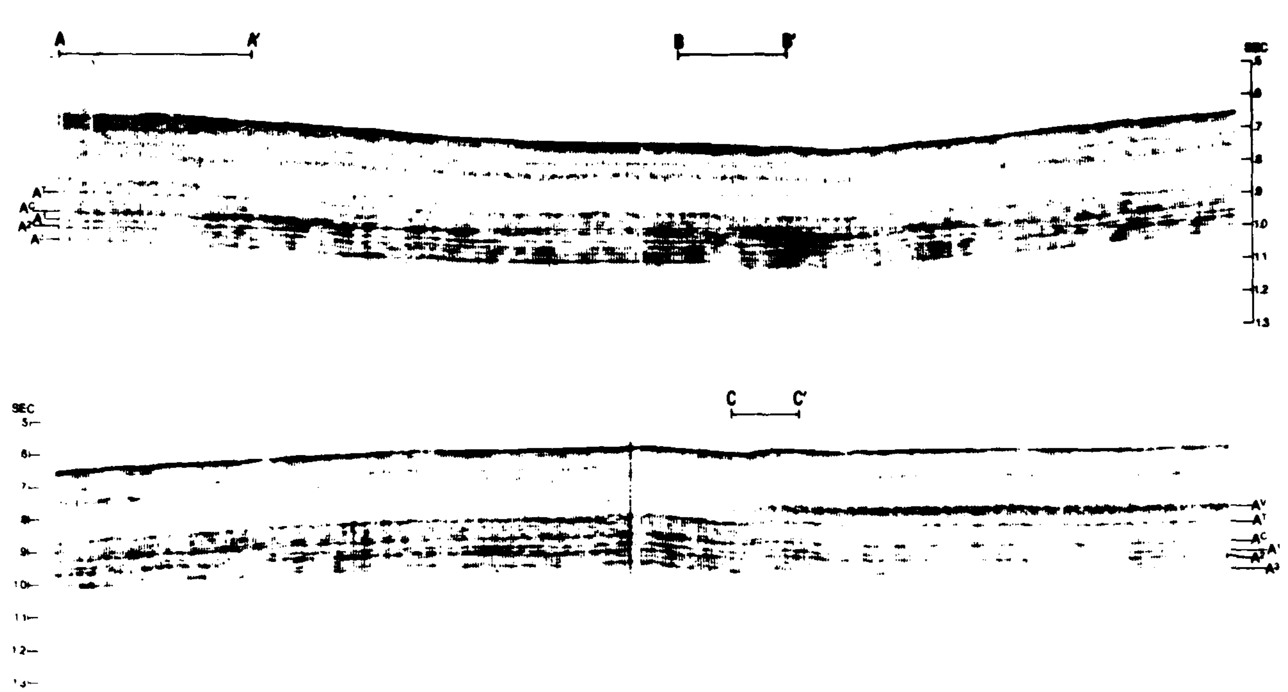

Fig. 2. DTAGS CSP section from the Bermuda Rise area. The total length of the profile presented is ~12 km with a nominal shot spacing of 15 m.

hydrophone group were used to confirm that each group was at its correct range; therefore, any horizontal array offsets are limited to an essentially linear deviation from the ship's trackline. For presentation purposes, the seismic sections in Figure 2 have been corrected to a standard shot-depth datum.

Stacking velocity estimates were made using 11 adjacent CSP gathers with a nominal shot spacing of 15 m. Figure 3 presents interval velocities and layer thicknesses based on mean stacking velocities [Dix, 1955] and reflection times for all measurements along this profile. Interval velocities between major reflection horizons for DSDP sites 386 and 387 [Tucholke et al., 1979] and associated lithostratigraphic columns are shown in Figure 3 for comparison purposes. The asterisk in the DSDP interval velocity columns of Figure 3 denote horizons which were not resolved in the DSDP single-channel reflection records.

Major Reflecting Horizons

DTAGS data resolved reflection horizons to ~0.5 sec of two-way travel time. Therefore, of the major reflectors identified in this region by Tucholke and Mountain [1979], we should observe only horizons A^V, A^T, and A^C. The northern and eastern parts of the track line are in the area where Tucholke and Mountain [1979] indicate that A^V (associated with volcanoclastic turbidites) is found. The reflector observed at 0.18 to 0.19 sec below the sea floor (Figure 2) is consistent with the arrival time of 0.195 sec for A^V at DSDP Site 386.

We relate the moderately strong reflector ~0.05 sec below A^V to the top of horizon A^T, the siliceous turbidites recovered at both DSDP Sites 386 and 387 (Figure 1). The sequence of strong, closely spaced parallel reflectors that begins with a moderately strong reflector at ~0.28-sec subbottom correlates with the layered limestones, claystones, chalk and chert, which Tucholke et al. [1979] associate with reflector A^C.

The siliceous turbidites, which are correlated with the A^T reflector by Tucholke et al. [1979], are 80 to 90 m thick at DSDP Site 386 and 48.6 m thick at DSDP Site 387 [Tucholke et al., 1975]. Using an estimated interval velocity of 1.7 km/sec and these thicknesses for the siliceous turbidites, the two-way travel time between the top of the A^T horizon to the top of the A^C horizon would range from 0.057 to 0.11 sec; our observations (Figure 2) are more consistent with Site 387 data, which suggests thinning of the A^T sequence to the south and west of Bermuda.

Discussion

These data from the Bermuda Rise validate the ability of DTAGS to achieve its design goals of resolving the structure of and P-velocity field within deep-ocean sediments. A comparison of DTAGS and conventional single-channel seismic reflection data from the same location is shown in Figure 4. Structural details resolved with DTAGS data include numerous reflection horizons; the rough sea floor found at the beginning of the section (A–A', Figure 2) that is most likely the edge of a mud wave [Embley et al., 1980]; and evidence of faulting within the sediment column (C–C', Figure 2), which may have controlled the deposition of volcanoclastic turbidites in this area.

DTAGS allows us to obtain detailed estimates of *in situ* P-velocity - depth functions within the upper 300-400 m of deep-ocean sediments. The P-velocity - depth functions we

MEAN VELOCITIES – POSITIONS C′ TO END OF SECTION
(8 CSP SAMPLES)

HORIZON	DTAGS MEAN STACKING VELOCITY (m/sec)	DTAGS THICKNESS (m)	DTAGS INTERVAL VELOCITY (m/sec)	DSDP SITE 386 INTERVAL VELOCITY (m/sec)	DSDP SITE 386 LITHOLOGY	DSDP SITE 386 AGE
BOTTOM	1522 ± 14					
		149 ± 26	1658 ± 300	1740	MARLY NANNO OOZE AND CLAY; ZEOLITIC-DTZOSE CLAY NANNO OOZE; CALCAREOUS TURBIDITES	QUATER; MIO U; OLIG U
A^V	1547 ± 17					
		52 ± 9	2079 ± 335	1940	VOLCANICLASTIC TURBIDITES	OLIG M, L
A^T	1576 ± 37					
		50 ± 8	1705 ± 276	1750	SILICEOUS TURBIDITES	EOCENE U
A^C	1583 ± 49					
		29 ± 1	2051 ± 68	1910	CALCAREOUS TURBIDITES	EOCENE MIDDLE
A^1	1596 ± 47					
		21 ± 3	2338 ± 399	•		
A^2	1610 ± 55					
		35 ± 2	2362 ± 102	•		
A^3	1633 ± 49					

MEAN VELOCITIES – POSITIONS A TO C′
(26 CSP SAMPLES)

HORIZON	DTAGS MEAN STACKING VELOCITY (m/sec)	DTAGS THICKNESS (m)	DTAGS INTERVAL VELOCITY (m/sec)	DSDP SITE 387 INTERVAL VELOCITY (m/sec)	DSDP SITE 387 LITHOLOGY	DSDP SITE 387 AGE
BOTTOM	1529 ± 19					
		175 ± 15	1632 ± 144	1666	HEMIPELAGIC CLAY; RADIOLARIAN MUD	QUATER; O (LOWER TO MIDDLE OLIGOCENE); EOCENE U
A^T	1547 ± 38					
		48 ± 1	1656 ± 40	•	SILICEOUS TURBIDITES	
A^C	1552 ± 49					
		24 ± 5	1892 ± 409	2010	CHERTY CLAYSTONE, SILICEOUS CLAYSTONE RADIOLARIAN MUDSTONE	EOCENE MIDDLE
A^1	1559 ± 48					
		19 ± 3	1869 ± 285	•		
A^2	1564 ± 52					
		42 ± 5	2105 ± 217	•		EOCENE LOWER
A^3	1582 ± 43					

Fig. 3. Interval velocities based on average stacking velocities and mean reflection horizon times are shown. The error bounds on interval velocities were computed using first-order stacking-velocity terms and assume errors in picking horizon times are negligible.

find support low P-velocity gradients in the upper 100 to 170 m of sediments (Figure 5). This result is more consistent with averaged DSDP logging results [Carlson et al., 1986] and Hydraulic Piston Core data (see, for example; Mayer, 1985) than with functions proposed by Hamilton [1985] for this type region (Figure 6). The data presented in Figure 6 also show the Purdy [1986] and Bryan [1980] high-resolution sediment models together with those determined using DTAGS data. These velocity-depth models emphasize the spatial variability that characterizes the sediment column both within and between geologic provinces.

The ability of the deep-tow multichannel technique to resolve the spatial variability of deep-ocean sediment properties provides a means by which investigators can constrain models of geologic processes; this includes constraints related to structure and those drawn from P-velocity - depth functions. For example, relating the low P-velocity gradient for

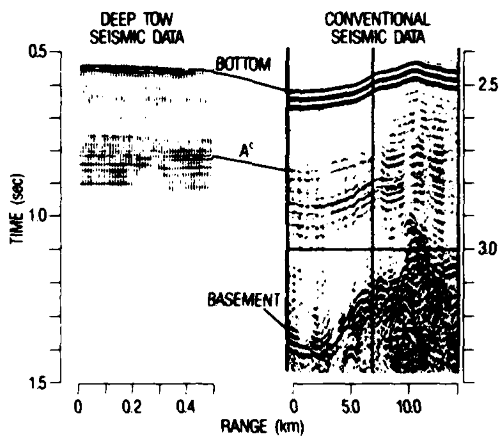

Fig. 4. DTAGS data from section B–B′ in Figure 2 are shown together with conventional seismic sparker data taken at the same location by USNS *Kane* on Cruise 343419.

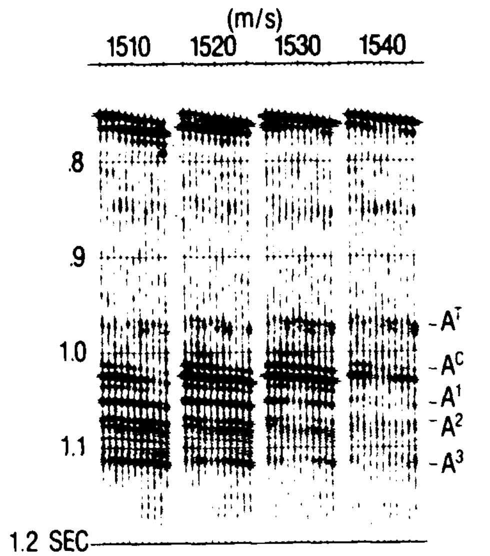

Fig. 5. CSP stacked traces from within region B-B′ (Figure 2) are shown. The stacking velocities for the bottom reflection and for horizon A^T are both ~1530 m/sec; this supports a low P-velocity gradient within the upper sediment column. The appropriate stacking velocity for horizon A^1 is ~1520 m/sec. This decrease in stacking velocity indicates a P-velocity inversion exists within the upper 300 m of the sediment column.

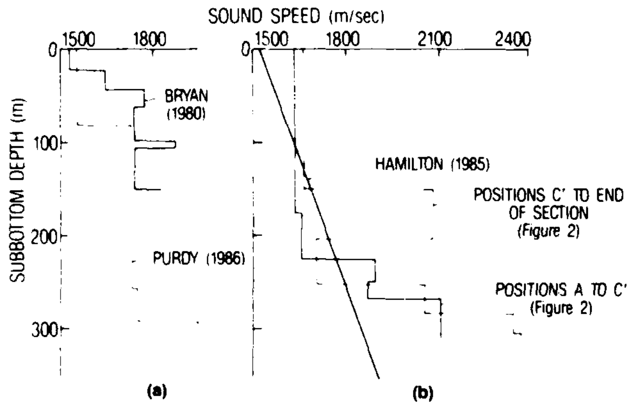

Fig. 6. (a) P-velocity - depth functions determined using bottom source and receiver seismic refraction profiles for the Nares Abyssal Plain [Bryan, 1980] and Kane Fracture Zone [Purdy, 1986]; (b) P-velocity - depth functions determined from DTAGS data and the Hamilton [1985] velocity - depth function appropriate for the DTAGS study region.

upper sediments on the Bermuda Rise (Figure 5) to the evidence for broad areas of underconsolidated sediments on the Rise [Silva and Booth, 1986] would make it possible to estimate the spatial variability of underconsolidation and, from that, predict areas of anomalously low sediment shear modulus.

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